Mapping Dark Matter with antiparticles

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Current status and goals

The existence of Dark Matter and the investigation of its nature plays a key role in understanding structure formation after the big bang and the energy density of the universe. Recent high precision PLANCK results show that the Dark Matter content is even larger than measured before. Dark Matter cannot be explained with known types of matter, therefore we are at the dawn of something significantly new. It is generally acknowledged that the identification of the nature of Dark Matter can only be achieved with a complimentary approach of direct, indirect, and collider searches probing parameter ranges from different observational angles. We have finally entered the era of Dark Matter discovery and experiments are reaching the sensitivities to probe the most interesting Dark Matter candidates and it is very likely that we transition into the era of precision Dark Matter physics within the next decades.
Well-motivated theories beyond the standard model of particle physics contain Dark Matter candidates that are able to annihilate with other Dark Matter particles into known particles and form an excess on top of the astrophysically produced spectra. Antiparticles without primary astrophysical sources are ideal candidates for such an indirect search. Latest results of major cosmic-ray instruments (PAMELA, Fermi, Atic, AMS-01) for the electron and positron fluxes as well as for photons from the galactic center (Fermi), unassociated with sources, show evidence of a structure that might be explained by Dark Matter. Interestingly, antiprotons do not show such a significant feature. Therefore, it is a very open question if these results will eventually be explained by astrophysical phenomena or Dark Matter models. The interpretation with the aforementioned particle species will remain ambitious as it depends on modeling the astrophysical continuum backgrounds. In addition, Dark Matter forms a halo around the galactic plane of up to 10 kpc radius while the astrophysical background is much more locally produced in the galactic disk. This emphasizes the need for a precise understanding of propagation and, on the other hand, that different Dark Matter annihilation products can be used as messengers from different regions of the dark matter distribution, e.g., positrons have a smaller reach than antiprotons due to stronger bremsstrahlung losses. Combining information from different messengers will therefore allow to draw a detailed picture of the exact dark matter distribution.

10 year perspective

The AMS experiment on the International Space Station will take the cosmic-ray spectroscopy in the interesting kinetic energy range for Dark Matter models to the next level. Among other particles, especially positrons and antiprotons will be measured in a large energy range with great precision. Propagational uncertainties will be drastically reduced and the backgrounds understood with high statistics. Also solar and geomagnetic effects will be systematically investigated. It will also be possible for the first time to reach sensitivity to probe predicted cosmic-ray antideuteron fluxes from Dark Matter annihilations. Low-energy antideuterons are the most unexplored indirect Dark Matter search channel and are a potential breakthrough approach for the identification. In contrast to other antiparticle channels, the astrophysical background is believed to be up to factor of 100 lower than the flux from Dark Matter annihilations. While AMS will reach sensitivity to probe the interesting range for the first time, especially the geomagnetic location of the ISS will make large systematic corrections for low-energy charged particles necessary. Independent confirmation and deeper reach will be provided by the planned GAPS balloon experiment using a different detection technique and flying at low geomagnetic cut-offs (i.e. Antarctica).

20 and 30 year perspective

The next 10 years of direct, indirect, and collider measurements will hopefully reveal more specifics about the Dark Matter particle properties. Looking back at the history of particle physics, the discovery experiments will be used as input to build precision experiments. For the case of antiparticle Dark Matter annihilation products this could result in, e.g., large acceptance, long measurement time, high background rejection, and low geomagnetic cut-off experiments with large sensitivities at low kinetic energies for antideuterons, at high energies for positrons, and at photon annihilation lines. For an ideal low-background environment this experiment could be placed on a favorable satellite orbit or even the Moon surface. Combined analysis of the different channels will allow to map the Dark Matter distribution.